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INTERNATIONAL APPLICATION NO.

PCT/IB97/00903

INTERNATIONAL FILING DATE

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PRIORITY DATE CLAIMED

19 July 1996

TITLE OF INVENTION :

BLIND DFE AND PHASE CORRECTION

APPLICANT(S) FOR DO/EO/US :

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Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371 (f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
- a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
- b. ☒ has been transmitted by the International Bureau.
- c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
- a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
- b. ☐ have been transmitted by the International Bureau.
- c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
- d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

## Items 11. to 16. below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A **FIRST** preliminary amendment.
14. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☒ Other items or information:  
Copies of International Application as published, International Search Report, International Preliminary Examination Report.

17. ☒ The following fees are submitted:**BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):**

Neither international preliminary examination fee (37 CFR 1.482)  
nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO  
and International Search Report not prepared by the EPO or JPO ..... **\$970.00**

International preliminary examination fee (37 CFR 1.482) not paid to  
USPTO but International Search Report prepared by the EPO or JPO ..... **\$840.00**

International preliminary examination fee (37 CFR 1.482) not paid to USPTO  
but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... **\$760.00**

International preliminary examination fee paid to USPTO (37 CFR 1.482)  
but all claims did not satisfy provisions of PCT Article 33(1)-(4) ..... **\$670.00**

International preliminary examination fee paid to USPTO (37 CFR 1.482)  
and all claims satisfied provisions of PCT Article 33(1)-(4) ..... **\$96.00**

**CALCULATIONS PTO USE ONLY****ENTER APPROPRIATE BASIC FEE AMOUNT**

\$ 840.00

Surcharge of **\$130.00** for furnishing the oath or declaration later than   20   ☒   30    
months from the earliest claimed priority date (37 CFR 1.492(e)).

\$ 130.00

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	
Total claims	22 - 20 =	2	X <b>\$18.00</b>	\$ 36.00
Independent claims	4 - 3 =	1	X <b>\$78.00</b>	\$ 78.00
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ <b>\$260.00</b>	\$

**TOTAL OF ABOVE CALCULATIONS**

\$ 1084.00

Reduction of ½ for filing by small entity, if applicable. A Small Entity Statement must also  
be filed (Note 37 CFR 1.9, 1.27, 1.28).

\$

**SUBTOTAL**

\$ 1084.00

Processing fee of **\$130.00** for furnishing the English translation later than   20     30    
months from the earliest claimed priority date (37 CFR 1.492(f)).

\$

**TOTAL NATIONAL FEE**

\$ 1084.00

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be  
accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **\$40.00** per property.

\$

**TOTAL FEES ENCLOSED**

\$ 1084.00

Amount to be:  
refunded \$  
charged \$

- a. ☒ A check in the amount of \$ 1084.00 to cover the above fees is enclosed.
- b. ☐ Please charge my Deposit Account No. 19-0743 in the amount of \$            to cover the above fees. A duplicate copy of this sheet is enclosed.
- c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 19-0743. A duplicate copy of this sheet is enclosed.

**NOTE:** Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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BLIND DFE AND PHASE CORRECTION

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FIELD OF THE INVENTION

The present invention relates to digital communication methods and systems.

BACKGROUND OF THE INVENTION

Modems for digital communications systems are designed to cope with various channel impairments. An essential element of the modem is the start-up process in which modem parameters such as equalizer taps, carrier frequency error, timing error, and gain setting, are estimated in order to provide the required modem performance.

In the prior art, two training modes are used: 1) using a known transmitted data sequence; 2) or using the transmitted information data without any prior knowledge of the value of the transmitted data. The latter mode is known as a blind start-up.

In the prior art, it is difficult to perform a blind start-up process, with limited computational resources and to converge to a good initial setting of the modem parameters for channels that exhibit severe linear distortion which gives rise to severe inter-symbol interference (ISI), and channels that suffer from severe narrow-band interference.

Therefore, there is a need in the art to provide a solution for the blind start-up process of a receiver in the context of digital communications signals in the presence of severe ISI and severe narrow-band interference. There is an additional need in the art to provide relief from ISI and severe narrow-band interference for conventional blind and non-blind modems.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for a digital communication receiver which is capable of operating over channels with severe ISI and narrow-band interference in either blind or non-blind modems.

The receiver of the present invention receives an analog signal modulated with digital information. The receiver converts the analog signal to a digital signal and demodulates the digital signal to recover the complex valued

components of the transmitted digital signal. The complex valued components are low pass filtered and passed through an adaptive pre-equalizer filter to reduce eigen value spread correlation.. The filtered complex valued signal is then subjected to a decision feedback equalizer which operates using a series of adaptive filters to additionally remove artifacts of inter-symbol interference. The resulting filtered and equalized complex valued signal is then converted to a digital signal to recover the digital information.

### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts a digital communications system which employs the invention in a preferred embodiment.

Figure 2 describes the transmitter in the preferred embodiment of Figure 1.

Figure 3 describes the structure of the receiver in the preferred embodiment.

Figure 4 describes the operation of the pre-equalizer filter unit of the receiver in the preferred embodiment.

Figure 5 describes operation of the DFE (Decision Feedback Equalizer) in the receiver of the preferred embodiment.

### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific preferred embodiments in which the inventions may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present inventions. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present inventions is defined only by the appended claims.

Reference is made to Figure 1 which illustrates a typical application of a digital communications system operating over UTP (Unshielded

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Twisted Pair) copper cables plant 102 or another communication medium such as coaxial cable. The present invention is applicable to many types of communication mediums, and in particular to a digital subscriber loop of a telephone network or a coaxial cable television infrastructure. The system comprises a transmitter 101 that receives a sequence 104 of data bits  $b[n]$ , and outputs a signal  $x(t)$  to the cable. A wired communications medium 102, such as a copper cable plant, connects the transmitter 101 to the blind receiver 103. The blind receiver 103 receives a signal  $y(t)$  from the communications medium 102 and outputs a sequence of detected digital data bits  $\hat{b}[n]$  105.

The communications medium or cable plant may have one or more unterminated wire drops 106, as illustrated in Figure 1, and these wire drops may cause severe reflections that distort the signal and introduce significant inter-symbol interference (ISI).

Reference is made now to Figure 2, which describes the structure of the transmitter 101. In figure 2, the single-lined arrows indicate the propagation of real valued signals and the double-lined arrows indicate the propagation of complex valued signals. Real valued signals are a subset of complex valued signals and thus whenever the term "complex valued" is used herein, it encompassed either imaginary or real valued signals or the combination of the two which is a complex valued signals. The transmitter 101 operates according to a general approach of linear transmission that particularly include any one of PAM (Pulse Amplitude Modulation), QAM (Quadrature Amplitude Modulation), PSK (Phase Shift Keying), CAP (Carrierless AM-PM), and NRZ (Non-Return to Zero) transmission methods, among others. The input data bits sequence  $b[n]$  is converted to a sequence of I-Q complex valued symbols,  $a[n]$ , by a bit-to-symbol conversion unit 201, that may comprise a scrambler, a differential encoder, a trellis or a block FEC (Forward Error Correction) encoder, a CRC error protection encoder, a framer, a shell mapper, and/or protocol layer units.

The sequence  $a[n]$  is then fed to a cascade of transmission filter 202, an up-converter 203, where it is multiplied by sine and cosine sequences

that are generated in the sine wave source 204, a Digital to Analog (D/A) converter 205, an analog LPF (Low Pass Filter) 206 whose cutoff frequency is designed to reject aliasing effects of the D/A, and an amplifier 207. The output of the transmitter is the analog signal  $x(t)$ .

- 5                   Reference is now made to Figure 3 which illustrates the structure of the blind receiver 103. The input to the blind receiver is an analog signal  $y(t)$  that has propagated through the wired communications medium 102, such as a copper cable plant. This signal may suffer from severe reflections and linear distortions and it may contain a high level of noise and interference components
- 10   due to e.g. narrow-band radio transmissions which occupy the same frequency band of the signal  $y(t)$ .

- The receiver input signal is low-pass filtered by the LPF 301 which is designed to combat sampling aliasing effects, then it is amplified by an amplifier 302 whose gain is automatically adjusted with an Automatic Gain
- 15   Control (AGC) to exploit the dynamic range of sampler, and then the signal is sampled by Analog to Digital converter (A/D) 303. The sampling phase of the A/D is adaptively controlled by a timing PLL (phase locked loop) 304, which adjusts the sampling phase so that the power of the A/D output is maximized. Those skilled in the art will readily recognize that the timing PLL 304 may
- 20   alternatively employ other conventional timing methods, such as decision directed timing.

- The A/D output sequence is then down-converted by multiplying it with sine and cosine sequences that are synthesized in a sine wave source 305, and the resulting I and Q components are low pass filtered by the LPFs 306 and
- 25   307. Both LPFs 306 and 307 are designed to remove the demodulation image, to remove out-of-band signals, and to match the response frequency of the cascade of the transmission pulse response of transmit filter 202 of a typical cable plant or other communication medium 102 upon which the system operates.

- The LPF units' outputs are then processed by a pre-equalizer filter
- 30   unit 310, whose operation is described below in conjunction with Figure 4, and a Decision Feedback Equalizer (DFE) unit 308, whose operation is described

below in conjunction with Figure 5. The output of the DFE unit 308 is a sequence of detected I-Q symbols  $\hat{a}[n]$  and an equalized sequence  $s_2[n]$ . These sequences are then processed by a symbol-to-bits conversion unit 309 that performs the inverse function of the bits-to-symbols conversion unit 201 and may employ a descrambler, differential decoder, FEC decoders, deframer, shell demapper, and/or a protocol layer decoder. The output of this unit is a sequence of the detected data bits  $\hat{b}[n]$  105.

Figure 4 illustrates the pre-equalizer filter unit 310. The input sequence of the unit,  $s_1[n]$  is filtered by a digital FIR (Finite Impulse Response) filter 401 with L taps  $p_n[1] \dots p_n[L]$  ( $L \geq 0$ ) where  $p_n[l]$  denotes the  $l$ -th tap after n iterations. The taps of the filter are adaptively adjusted by an adaptation unit 402. The adaptation rule is:

$$p_{n+1}[l] = p_n[l] + \Gamma_n (s_2[n]) s_1^* [n-l] \quad l = 1 \dots L$$

where  $s_2[n]$  is the output of the FIR filter 401, and where  $\Gamma_n(x)$  is a possibly nonlinear function 403 whose parameters may vary with the iteration index n. A recommended class of  $\Gamma$  function is:

$$\Gamma_n(x) = \delta_p[n] \cdot x$$

where  $\delta_p[n]$   $n = 1, 2, \dots$  is a sequence of step sizes. The signal undergoes the following transformation:

$$s_2[n] = s_1[n] + \sum_{l=1}^L p_n[l] s_1[n-l] \quad (L \geq 0)$$

The input signal for the pre-equalization filter unit 310 is denoted  $s_1[n]$  in Figure 4 and is routed to the FIR filter 401, the adaptation unit 402 and to summation circuit 404.  $s_1[n]$  is combined with the output of the adaptive FIR filter 401 to produce the output signal  $s_2[n]$  of the pre-equalization filter unit 310. The non-linear circuit 403 modifies the  $s_2[n]$  signal to provide the feedback to adjusting the taps of adaptive FIR filter 401.

Figure 5 illustrates the DFE (Decision Feedback Equalizer). The DFE's input sequence  $s_2[n]$  is first rotated by an adaptive rotator 501, by an

- angle  $\theta[n]$ . The rotated sequence is then filtered by an FFE (Feed Forward Equalizer) FIR filter 502 whose taps' values are  $c_n[1]..c_n[M]$  ( $M \geq 1$ ), to produce output signal  $s_3[n]$ . Signal  $s_3[n]$  is then summed 507 with the output of an adaptive FIR filter 504 whose taps are  $d_n[1]..d_n[N]$ ,  $N \geq 0$ , and which is driven by the sequence of detected symbols  $\hat{a}[n]$ . The result of this summation is equalized sequence  $s_5[n]$ , 506. The sequence 506 is fed to a symbol detector 503 that employs a memoryless nearest neighbor decision rule, based on the transmitted symbols' I-Q constellation to generate the sequence  $\hat{a}[n]$ . We note that in this preferred embodiment, a single memoryless decision rule is employed.
- 10 However, the present invention can be employed in a receiver that employs a more accurate detection scheme such as an approximate nearest sequence detector which is the maximum likelihood sequence estimator when the noise of the input of unit 503 has a Gaussian distribution.

- The parameters of units 501, 502 and 504 are jointly updated by
- 15  $S_5[n]$  to combat ISI (Inter-Symbol Interference) and noise. The adaptation scheme is the following:

$$\begin{aligned}\theta[n+1] &= \theta[n] + \rho_n(s_5[n]) \\ c_{n+1}[m] &= c_n[m] + \varphi_n(s_5[n])s_3^*[n-m] \quad m = 1..M \\ d_{n+1}[i] &= d_n[i] + \Psi_n(s_5[n])\hat{a}^*[n-i] \quad i = 1..N\end{aligned}$$

where  $\rho_n(x)$ ,  $\varphi_n(x)$ , and  $\Psi_n(x)$  are possibly nonlinear complex valued scalar function whose parameters may depend on the iteration index  $n$ , and  $M \geq 1$ ,  $N \geq 0$ .

- 20 The adaptation functions in this embodiment are:



$$\varphi_n(x) = \begin{cases} \delta_c[n](x - \hat{a}(x)) & n > T_2^c \\ \delta_c[n](|x|^2 - k_1)x & T_1^c \leq n < T_2^c \\ \delta_c[n](\text{Re}^2(x) - k_2)\text{Re}(x) & n < T_1^c \end{cases}$$

$$\rho_n(x) = \begin{cases} \delta_\theta[n](\text{Re}^2(x) - k_2)\text{Re}(x)\text{Im}(x) & n < T_1^\theta \\ \delta_\theta[n]\text{Im}(\hat{a}(x)x^*) & n \geq T_1^\theta \end{cases}$$

$$\Psi_n(x) = \begin{cases} \delta_d[n](x - \hat{d}(x)) & n > T_2^d \\ \delta_d[n](|x|^2 - k_1)x & T_1^d \leq n < T_2^d \\ \delta_d[n](\text{Re}^2(x) - k_2)\text{Re}(x) & n < T_1^d \end{cases}$$

where  $\delta_c[n]$ ,  $\delta_d[n]$  and  $\delta_\theta[n]$ ,  $n = 1, 2, \dots$ , are sequences of real-valued step sizes,

- 5 where  $k_1$  and  $k_2$  are real valued scalars, and where  $\text{Re}(\cdot)$  and  $\text{Im}(\cdot)$  denote the real part and the imaginary part of a complex scalar, and where  $\hat{a}(x)$  is the result of a memoryless nearest neighbor symbol detector whose input is  $x$ .  $T_1^c$ ,  $T_2^c$ ,  $T_1^\theta$ ,  $T_2^\theta$  and  $T_1^d$  and  $T_2^d$  are positive scalars.

- The sequences  $s_1[n], \dots, s_5[n]$ ,  $\hat{a}[n]$  may be calculated at the symbols  
 10 rate (T-spaced receiver). Alternatively  $s_2[n]$ ,  $s_3[n]$  and  $s_4[n]$  may be calculated at a higher rate (Fractionally spaced receiver). The resulting outputs of units 501, 502 and 504 are described as follows:

$$s_3[n] = s_2[n] \cdot e^{j\theta[n]}$$

5

$$s_4[n] = \sum_{m=1}^M c_n[m] s_3[n-m]$$

10

$$s_5[n] = s_4[n] + \sum_{l=1}^N d_n[l] \hat{a}[n-l]$$

### CONCLUSION

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. This patent is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

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We Claim:

1. A communication receiver, comprising:  
an input receiving a modulated analog signal containing digital information;
- 5 a front end unit operable for performing analog to digital conversion, for performing demodulation and for performing timing control, and further operable for producing a demodulated complex-valued digital signal from the modulated analog signal;  
a digital equalizer connected for receiving the demodulated complex  
10 valued digital signal, comprising:  
a first filter operable receiving the demodulated complex valued digital signal;  
a second filter connected to the first filter and operable for  
reducing the amount of noise and inter symbol interference in the  
15 demodulated complex valued digital signal; and  
a symbol-to bit converter connected to the second filter.
2. The communication receiver according to claim 1 wherein the first filter  
operates to reduce the eigenvalue spread of an input spectrum of the  
20 demodulated complex valued digital signal.
3. The communication receiver according to claim 1 wherein the second  
filter is further operable for reducing the amount of noise and inter symbol  
interference of the demodulated complex valued digital signal without training  
25 data.
4. The communication receiver according to claim 1 wherein the second  
filter further includes a rotator for restoring the phase of the demodulated  
complex valued digital signal without the use of training data.

5. The communication receiver according to claim 1 wherein the second filter further includes a nonlinear feedback network for removing the inter-symbol interference without the use of training data in the demodulated complex valued digital signal.

6. The communication receiver according to claim 1 wherein the first filter further comprises an L-tap Finite-Impulse-Response (FIR) Filter, where  $L \geq 1$ , whose first tap is set to a fixed value, and the filter's taps are adjusted so that its output power is minimized.

7. The communication receiver according to claim 1 wherein the second filter further comprises an M-tap FIR filter whose taps are adjusted according to the following formula:

$$c_{n+1}[m] = c_n[m] + \varphi_n(s_3[n]) s_3^*[n-m] \quad m = 1 \dots M$$

where  $c_n[m]$  is the m-th tap of the second filter after calculation of n outputs,

15  $s_3[n]$  is the input sequence to the second filter,  $s_3[n]$  is the sum of the output of the second filter and a decision feedback filter, and  $\varphi_n(\bullet)$  is a complex valued function, whose parameters may depend on the symbol index n.

and the decision feedback filter is an N-tap backward FIR-filter whose taps are adjusted according to the following formula:

$$d_{n+1}[i] = d_n[i] + \Psi_n(s_3[n]) \hat{a}^*[n-i] \quad i = 1 \dots N$$

20 where  $d_n[i]$  is the i-th tap of the decision feedback filter after calculation of n outputs,  $\hat{a}[n]$  is a sequence of detected data, and  $\Psi_n(\bullet)$  is a complex valued function, whose parameters may depend on the symbol index n.

8. The communication receiver according to claim 7, wherein for some  
25 values of n:

$$\varphi_n(x) = \delta[n] \left( \operatorname{Re}^2(x) - k_2 \right) \operatorname{Re}(x)$$

where  $\operatorname{Re}(\cdot)$  denotes the real part of a complex number,  $k_2$  is a scalar, and  $\delta[n]$   $n = 1, 2, \dots$  is a sequence of numbers.

9. The communication receiver according to claim 7, where for some values  
5 of  $n$ :

$$\varphi_n(x) = \delta[n] \left( |x|^2 - k \right) (x)$$

where  $k$  is a scalar, and  $\delta[n]$  is a sequence of numbers.

10. The communication receiver according to claim 7, where some values  
of  $n$ :

$$\varphi_n(x) = \delta[n] \left( x - \hat{a}(x) \right)$$

- 10 where  $\hat{a}(x)$  is the result of a memoryless nearest neighbor symbol detector whose  
input is  $x$ , and  $\delta[n]$  is a sequence of numbers.

11. The communication receiver according to claim 7, where some values  
of  $n$ :

$$\Psi_n(x) = \delta[n] \left( \operatorname{Re}^2(x) - k \right) \operatorname{Re}(x)$$

- 15 where  $k$  is a scalar, and  $\delta[n] = 1, 2, \dots$  is a sequence of numbers.

12. The communication receiver according to claim 7, where for some values  
of  $n$ :

$$\Psi_n(x) = \delta[n] (|x|^2 - k)(x)$$

where  $k$  is a scalar, and  $\delta[n]$  is a sequence of numbers.

13. The communication receiver according to claim 7, where some values of  $n$ :

$$\Psi_n(x) = \delta[n] (x - \hat{a}(x))$$

5 where  $\hat{a}(x)$  is the result of a memoryless nearest neighbor symbol detector whose input is  $x$ , and  $\delta[n]$  is a sequence of numbers.

14. The communication receiver according to claim 1, wherein the second filter further comprises:

10 an adaptive rotator connected to receive the demodulated complex valued digital signal;

an adaptive feed forward equalizer finite impulse response filter connected to the adaptive rotator;

15 a signal summation circuit connected to the adaptive feed forward equalizer finite impulse response filter and to an adaptive finite impulse response filter, the output of which is connected to update the adaptive rotator, the an adaptive feed forward equalizer finite impulse response filter and the adaptive finite impulse response filter;

20 a symbol detector connected to the signal summation circuit and the symbol-to-bit convertor; and

the adaptive finite impulse response filter connected to the symbol detector and operable for adapting to the summation result of the signal summation circuit.

15. The communication receiver according to claim 1, wherein the modulated analog signal is a modulation type selected from the group consisting of PAM (Pulse Amplitude Modulation), QAM (Quadrature Amplitude Modulation), PSK (Phase Shift Keying), CAP (Carrierless AM-PM), NRZ (Non-Return to Zero), offset-QPSK, and  $\pi/4$ -QPSK.
16. A digital communication receiver, comprising:
- a input stage receiving an analog signal containing digital information;
  - an analog to digital converter connected for producing a complex-valued digital signal from the modulated analog signal;
  - a demodulator connected for producing a demodulated complex-valued digital signal from the complex-valued digital signal;
  - a pre-equalizer filter connected to receive the demodulated complex-valued digital signal, comprising:
    - a first adaptive finite response filter having an output, having a tap adjustment input and connected to receive the demodulated complex-valued digital signal;
    - a first summation circuit connected to sum the demodulated complex-valued digital signal with the output of the first adaptive finite response filter to produce a pre-equalized complex-valued signal;
    - a function circuit connected to receive the pre-equalized complex-valued signal and operable for producing therefrom a non-linear response to the pre-equalized complex-valued signal;
    - an adaptation unit connected to receive the demodulated complex-valued digital signal, connected for receiving the non-linear response and connected to the tap adjustment input of the adaptive finite response filter to provide an adjustment to the first adaptive finite response filter;
    - a digital decision feedback equalizer connected to receive the pre-equalized complex-valued signal, comprising:
      - a rotator having an adaptive input and connected to receive the pre-equalized complex-valued signal and operable for restoring the phase

of input data contained in the pre-equalized complex-valued signal without the use of training data;

a feed forward equalizer finite input response filter having an adaptive input, an input connected to the rotator, an output, and operable for adaptively reducing the amount of noise and inter-symbol interference in the pre-equalized complex-valued signal;

a second summation circuit connected to sum the output of the feed forward equalizer finite input response filter with the output of a second adaptive finite response filter and for producing therefrom a corrected complex-valued signal;

a symbol detector connected to receive the corrected complex valued signal and to produce a symbol signal;

the second adaptive finite response filter having an output, an adaptive input and connected to receive the symbol signal;

wherein the corrected complex-valued signal is connected to the adaptive input of the rotator, the adaptive input of the feed forward equalizer finite input response filter and the adaptive input of the second adaptive finite response filter; and

a symbol-to-bit converter connected to receive the symbol signal and to

produce therefrom digital bits corresponding to the digital information.

17. A method of receiving a digital communication signal in the presence of inter-symbol interference, comprising the steps of:

receiving an analog signal modulated with digital information;

converting the analog signal to produce a digital signal;

multiplying the digital signal with sine and cosine signals to produce a complex-valued digital signal;

adaptively pre-equalizing the complex-valued digital signal to produce a pre-equalized complex-valued digital signal;



adaptively equalizing the pre-equalized complex-valued signal to reduce the inter-symbol interference and to produce a corrected complex valued symbol signal; and

converting the corrected complex valued symbol signal to the digital  
5 information.

18. The method according to claim 17, wherein the step of adaptively pre-equalizing further comprises the steps of:

adaptively filtering the complex-valued digital signal with an  
10 adaptive filter to produce a filtered complex-valued digital signal

summing the complex-valued digital signal with the filtered complex-valued digital signal to produce the pre-equalized complex-valued digital signal;

producing a non-linear response to the pre-equalized complex-valued signal; and  
15

modifying taps of the adaptive filter in response to the non-linear response to the pre-equalized complex-valued signal and in response to the complex-valued digital signal.

20 19. The method according to claim 17, wherein the step of adaptively equalizing further comprises the steps of:

adaptively rotating the pre-equalized complex-valued signal to produce a rotated complex valued signal;

adaptively filtering the rotated complex valued signal to produce  
25 a filtered rotated complex valued signal;

summing the filtered rotated complex valued signal with an adapted filter output to produce an adapted complex-valued signal;

detecting the symbols in the adapted complex-valued signal to produce the corrected complex valued symbol signal; and

30 producing the adapted filter output by adaptively filtering the corrected complex valued symbol signal.

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20. A communication system, comprising:  
a digital communications transmitter;  
a communications medium; and  
a digital communications receiver, comprising:
- 5 a input receiving a modulated analog signal containing digital information;  
an analog to digital converter connected for producing a complex-valued digital signal from the modulated analog signal;  
a demodulator connected for producing a demodulated complex valued digital signal from the complex valued digital signal;
- 10 a digital equalizer connected for receiving the demodulated complex valued digital signal, comprising:  
a first filter operable receiving the demodulated complex valued digital signal;
- 15 a second filter connected to the first filter and operable for reducing the amount of noise and inter symbol interference in the demodulated complex valued digital signal; and
- 20 a symbol-to bit converter connected to the second filter.
21. The communication receiver according to claim 1 wherein the receiver is used with a digital subscriber loop of a telephone network.
22. The communication receiver according to claim 1 wherein the receiver is used with a coaxial cable television infrastructure.

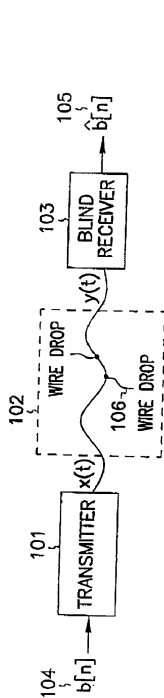


FIG. 1

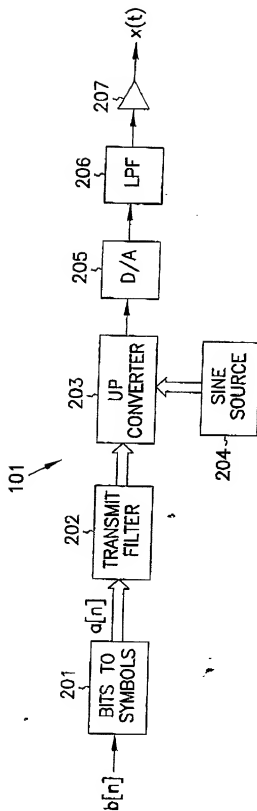


FIG. 2

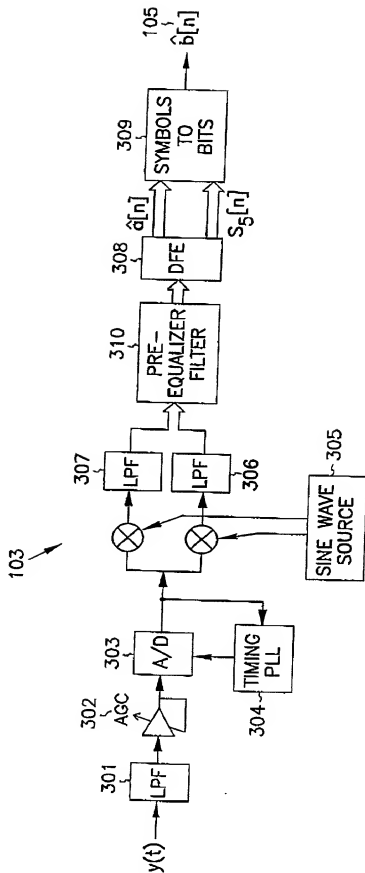


FIG. 3

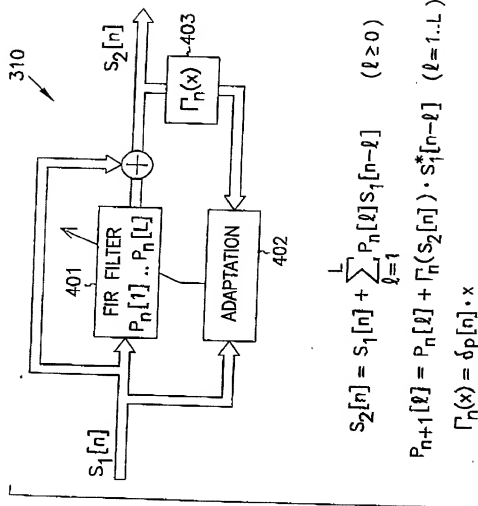


FIG. 4

$$S_2[n] = S_1[n] + \sum_{\ell=1}^L P_n[\ell] S_1[n-\ell] \quad (\ell \geq 0)$$

$$P_{n+1}[\ell] = P_n[\ell] + \Gamma_n^*(S_2[n]) \cdot S_1^*[n-\ell] \quad (\ell = 1..L)$$

$$\Gamma_n(x) = \delta p[n] \cdot x$$

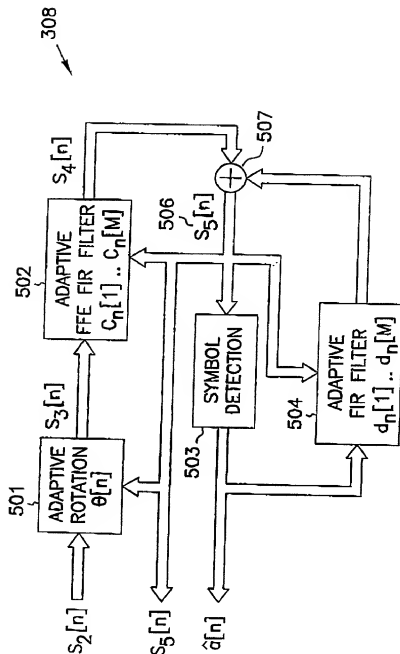


FIG. 5

$$S_3[n] = S_2[n] \cdot e^{j\theta[n]}$$

$$e[n+1] = \theta[n] + \rho_n(S_5[n])$$

$$M$$

$$S_4[n] = \sum_{m=1}^M C_n[m] S_3[n-m]$$

$$C_{n+1}[m] = C_n[m] + \rho_n(S_5[n]) S_3^*[n-m]$$

$$S_5[n] = S_4[n] + \sum_{i=1}^N d_n[i] \hat{a}[n-i], \quad d_{n+1}[i] = d_n[i] + \rho_n(S_5[n]) \hat{a}^*[n-i] \quad (M \geq 1, N \geq 0)$$

# United States Patent Application

## COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; that

I verily believe I am the original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled: BLIND DFE AND PHASE CORRECTION.

The specification of which was filed on January 19, 1992 as application serial no. 09/230,062.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56 (see page 4 attached hereto).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on the basis of which priority is claimed:

No such claim for priority is being made at this time.

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below.

Application Number  
60/092,195

Filing Date  
July 19, 1996

I hereby claim the benefit under Title 35, United States Code, § 120/365 of any United States and PCT international application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

Application Number  
PCT/IB97/00903

Filing Date  
July 18, 1997

Status  
Pending

I hereby appoint the following attorney(s) and/or patent agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith:

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I hereby authorize them to act and rely on instructions from and communicate directly with the person/assignee/attorney/firm/organization/who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented unless/until I instruct Schwegman, Lundberg, Woessner & Kluth, P.A. to the contrary.

Please direct all correspondence in this case to Schwegman, Lundberg, Woessner & Kluth, P.A. at the address indicated below:

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Jur Ref: 299.004US2  
erial No. 09/230,069  
iling Date: January 19, 1999

Page 2 of 3

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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